

3 Assessment and Characterization of Damages

The general types of damages the BPAT observed as a result of Hurricane Georges in Puerto Rico are discussed below. More detailed descriptions of the damage observed are included in Sections 4, 5, 6, and 7.

3.1 Wind Effects

The National Weather Service (NWS) reported wind speeds from Hurricane Georges varying from 109 mph to 133 mph (3-second peak gust at a height of 33 feet) as it crossed the island of Puerto Rico. NWS recorded wind speeds at different airports using the Automatic Surface Observing System (ASOS). Since ASCE 7-95 uses 3-second gust wind speeds at 33 feet above ground over flat open terrain conditions, all data recorded under different conditions were transformed to the ASCE 7-95 averaging time and height for comparison purposes. Based on recorded data and BPAT observations, the wind speeds experienced in Puerto Rico during Hurricane Georges did not exceed the basic design wind speed of Planning Regulations 7's 110 mph fastest-mile (133 mph 3-second gust). In addition to this basic design wind speed, an overload factor of 1.3 for light structures and an importance factor of 1.15 for essential facilities are applied, resulting in a higher wind speed for failure.

The siting of structures affected the wind forces that acted upon the building. Lower areas were sometimes shielded from winds by hills or mountains. Buildings on high exposed slopes appeared to receive higher wind speeds because of the speedup of the wind up the slopes of the hills or mountains (due to topographic effects and described in ASCE 7-95) (Figures 3-1 and 3-2). The significance of these topographical effects is not recognized in Planning Regulation 7, but is accounted for in the newly adopted 1997 UBC. The 1997 UBC references ASCE 7-95 for the determination of wind speeds. These wind speeds may be adjusted to incorporate topographic effects on wind speeds.

Doppler weather radar detected three possible tornado events in Vieques, Orocovi, and Jayuya. The output given by Doppler weather radar, which is based on algorithms, is interpreted by meteorologists who decide whether or not a tornado warning should be issued. Sometimes, a circulation detected by Doppler radar that occurs at great elevations may never touch ground. The BPAT members investigated building damage in and around these towns and found no evidence of tornadoes, such as debris spread in a radial manner and/or severely shredded or pulverized debris, indicative of a tornado on the ground.



FIGURE 3-1 The abrupt change in topography in this community outside Loiza caused a speedup in the wind that flows over and around the buildings located on the hill beyond. The wind load provisions of Planning Regulation 7 did not account for wind speedup caused by abrupt changes in topography, and therefore underestimated wind loads on buildings situated on hills, mountains, or escarpments.



FIGURE 3-2 Wind damage from Hurricane Georges to residential buildings in Puerto Rico. Blue FEMA tarps have been placed on many of the roofs that sustained damage.

3.2 Riverine and Coastal Flooding

Flood damage was observed mainly along rivers in the west and central areas of Puerto Rico, including Utuado, Jayuya, Adjuntas, Mayagüez, Añasco, and Arecibo. Coastal flooding was noted along the western shore at Rincón and Mayagüez. Damage in these areas occurred to buildings constructed without sufficient elevation above the BFE.

Flooding damage fell into two categories: buildings inundated by floodwaters that caused much of the building and contents to be wet, but no structural damage; and buildings with structural damage, where the foundations were undermined by floodwaters. Almost all flood-damaged homes fell into the first category. Figure 3-3 shows a typical non-elevated structure in a community located entirely in an SFHA that was damaged by Hurricane Georges. Figure 3-4 depicts a flood control measure that protected homes on one side of the river. Figure 3-5 is an example of the damage caused to the area along the river opposite the floodwall in Figure 3-4. Although these homes were severely flooded, they experienced minimal to no structural damage. Figures 3-6 and 3-7 illustrate cases where flooding undermined the building foundations.



FIGURE 3-3 Typical non-elevated structures in a community located entirely in an SFHA.



FIGURE 3-4 This flood gate located in Adjuntas prevented backwater from flooding homes located behind it; however, the wall contributed to flooding in the community located on the opposite side of the river, as shown in Figure 3-5.



FIGURE 3-5 Residential area on the opposite side of the river from the floodwall in Figure 3-4. The flooding in this area reached a depth of 5 feet.



FIGURE 3-6 Floodwaters eroded soil and undermined the foundation system of this building.



FIGURE 3-7 Riverbank erosion resulted in the undermining of the building foundations of a school (pink building) and house (white building) in Jayuya.

Siting of homes in floodprone areas, such as river and stream beds, was observed throughout Puerto Rico. Figure 3-8 illustrates a home constructed adjacent to and over an existing stream. Structures constructed in this manner are vulnerable to damage from floodwaters.



FIGURE 3-8 Typical construction adjacent to and over the river. Note the debris trapped under the concrete foundation and between the framing.

NFIP regulations and Planning Regulation 13 require that the lowest floor of structures located in A-Zones must be elevated to the BFE. However, in some flooded areas many buildings were not elevated to the required elevation. In many cases, the flooded structures may have been built before the FIRMs were issued. Homes were damaged due to improper elevation in coastal areas (Figure 3-9). Proper elevation techniques for construction in A-Zones are presented in Figure 3-10. A comparison of some of the differences in NFIP requirements for construction in V-Zones and A-Zones is presented in Figure 3-11.



FIGURE 3-9 Structure along the coast damaged by storm surge and wave action.

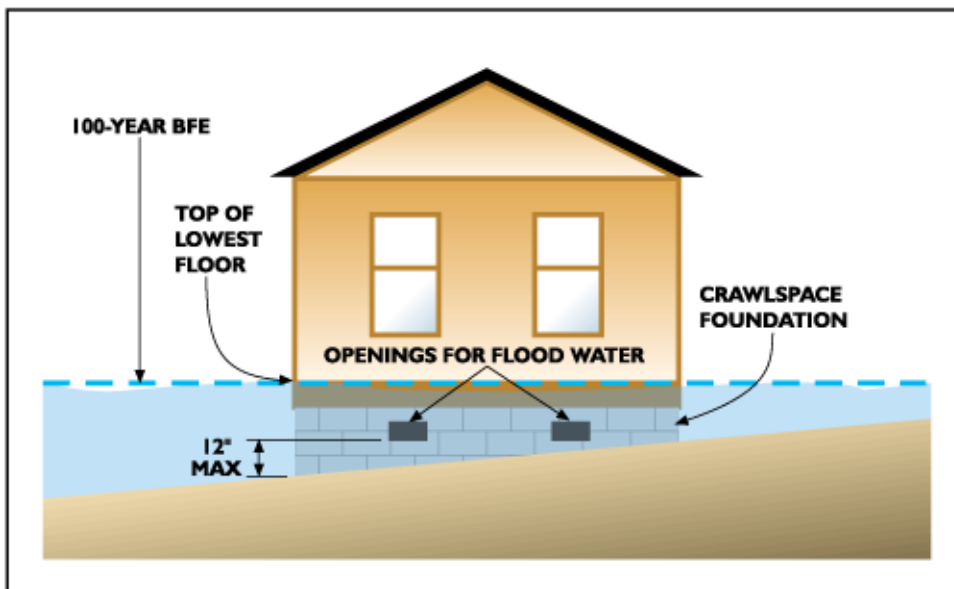


FIGURE 3-10 The top of the lowest floors of buildings in A-Zones must be at or above the BFE. Foundation walls below the BFE must be equipped with openings that allow the entry of flood waters so that interior and exterior hydrostatic pressures can equalize.

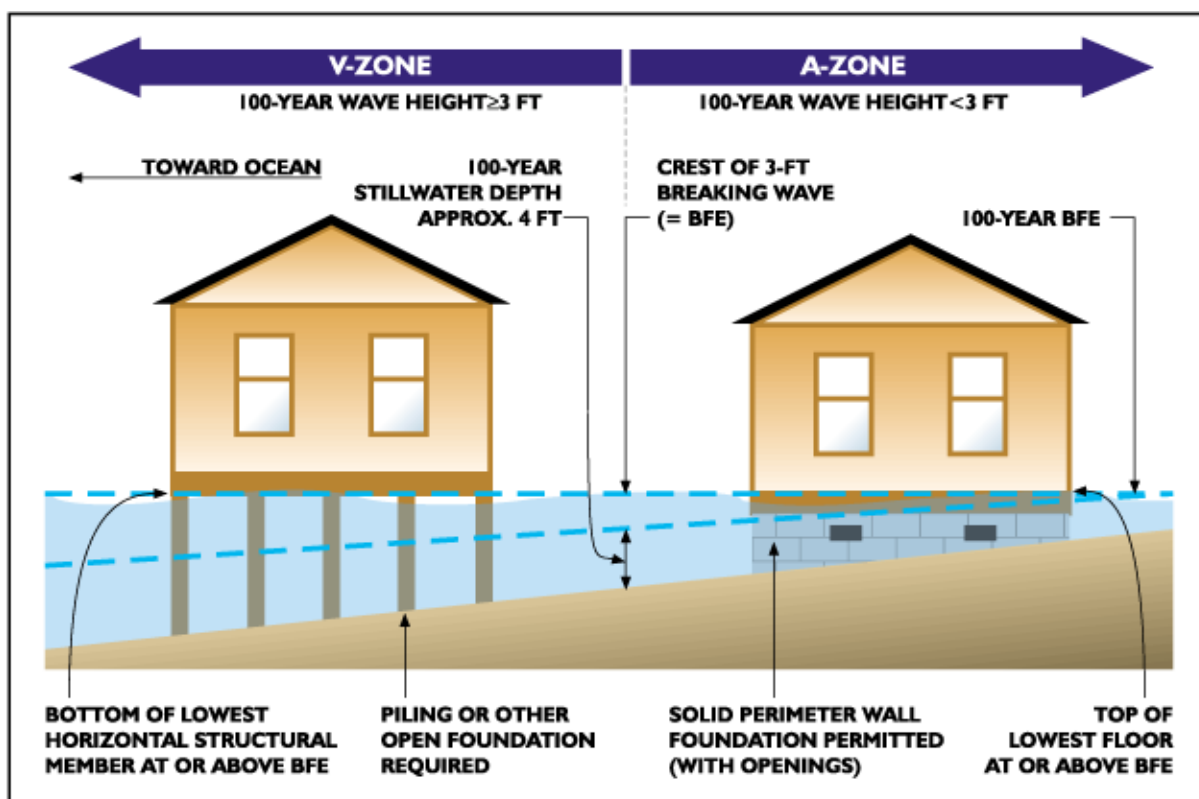


FIGURE 3-11 Comparison of building foundation and elevation requirements in V-Zones and A-Zones.

Buildings were not the only structures affected by the flooding of Hurricane Georges. Infrastructure, such as bridges and roadways, was also damaged. Three major bridges and a number of small bridges were washed-out and impassible. A bridge damaged by floodwaters outside Adjuntas is shown in Figure 3-12 and a severely damaged water treatment facility is shown in Figure 3-13.



FIGURE 3-12 This bridge outside Adjuntas collapsed due to insufficient design to resist the effects of floodwaters.



FIGURE 3-13 Severely damaged water treatment facility located in the floodplain in Jayuya; floodwaters overtopped the concrete wall.

3.3 Landslides

Puerto Rico's steep topography and shallow, sandy soils over bedrock make it susceptible to landslides. During Hurricane Georges, widespread rainfall in the more mountainous regions of the island resulted in numerous landslides that blocked and undermined roads, and even destroyed homes (Figures 3-14 and 3-15). This will become a greater problem in the future as more developments and houses are constructed in regions prone to such risks. A more detailed review and analysis of this problem needs to be undertaken. Figure 3-16 illustrates problems with unrestricted development. Many single-family homes are located beneath a cut that is void of vegetation, making the slope susceptible to landslides.



FIGURE 3-14 Aerial view of a now uninhabitable house caught in a landslide.



FIGURE 3-15 A landslide inundated this house with up to 5 feet of soil.



FIGURE 3-16 Development adjacent to a representative unprotected cut; the potential for future landslide activity exists.

3.4 Overview of Buildings Evaluated

The BPAT investigated residential and commercial buildings that were affected by wind, riverine and coastal flooding, and landslides. These buildings can be categorized into four types of construction:

- Concrete/masonry structures with concrete roof decks (residential and commercial).
- Concrete/masonry structures with wood-frame roof structures (residential and commercial).
- Combination structure, concrete foundation/first floor with wood-frame structure for the additional levels.
- All wood-frame structures.

The structural performance of buildings constructed of concrete/masonry with concrete roof decks was excellent. This was true for residential and commercial buildings. Residential buildings and homes constructed of concrete/masonry with wood-frame roof structures experienced widespread roof loss.

The all wood-frame structures, almost exclusively residential construction, performed worse than all others and the greatest amount of destruction was observed in them. Residential buildings investigated ranged in age from post-WWII to current day construction. Most mid- to high-rise buildings inspected were constructed during and since the 1960's.

3.4.1 Concrete/Masonry Structures with Concrete Roof Decks

Both residential and commercial buildings constructed of concrete/masonry with concrete roof decks were investigated. Figure 3-17 shows commercial buildings of concrete construction with concrete roof structures. These large buildings performed well structurally during Hurricane Georges. Many, however, experienced significant interior damage and property loss due to breach of the building envelope. Loss of exterior windows due to wind and windborne debris was the primary damage observed (Figure 3-18).



FIGURE 3-17 Commercial concrete structures with no structural damage. These structures are located to the east of Old San Juan.



FIGURE 3-18 Commercial concrete structure with interior damage due to breach of building envelope (failed windows). Note: Plywood sheets were installed after the storm to cover broken windows; they were not present prior to the storm.

The BPAT observed that single-family homes constructed of concrete, masonry, (or a combination of both) and with concrete roofs performed well with no structural damage (Figure 3-19). These structures were primarily one- and two-story buildings with reinforced concrete columns/piers and both reinforced and un-reinforced concrete masonry units (CMU) block pier foundations supporting elevated concrete floor slabs.

For the purposes of this report, systems used to protect doors and windows from missiles (windborne debris) are referred to as “shutter systems”. Shutter systems observed on the island varied in material and included plywood sheeting, corrugated metal, and pre-engineered metal and plastic panel systems. In Puerto Rico, these temporary shutter systems are commonly referred to as “hurricane panels”.



FIGURE 3-19 Residential concrete structure in the mountains north of Adjuntas with no structural damage following Hurricane Georges.

The first floor of concrete/masonry buildings with reinforced concrete roof decks often were elevated a single story or more above the ground on minimally reinforced columns. As a result, they are at significant risk from collapse during a major earthquake. The successful performance of these buildings during Hurricane Georges appears to relate mainly to the dead load from the weight of the concrete roofs and walls that helped resist uplift and lateral wind loads. The size and spacing of reinforcing steel was noted by the BPAT on buildings under construction, and the connections appeared to be based solely on gravity loads and the minimum connections of reinforcing steel for gravity loads. The BPAT observed a general lack of attention to lateral loads in all residential construction. For wood-frame houses, this lack of attention was evident in the amount of hurricane damage they received.

3.4.2 Concrete/Masonry Structures with Wood-Frame Roof Structures

Buildings with walls constructed of concrete/masonry columns with masonry infill and wood-frame roof structures were observed. This construction type is commonly found in Puerto Rico. Buildings of masonry construction with wood roof framing have performed well in other hurricane-prone areas of the United States when a continuous load path is present to transfer wind-induced loads from the roof structure to the foundation. Generally, the BPAT found that there was no attention to a continuous load path (for wind or seismic loads) in the roof structures other than for gravity loads. The sill plate atop the masonry wall was generally attached by extending reinforcing steel through a hole bored in the sill plate and bending the steel to prevent withdrawal, uplift, or displacement of the sill plate.

Most roofs inspected were gable roofs; the remainder were low-slope (flat roofs) and hipped roofs. Figure 3-20 represents a single-family home with a wood-frame gable roof structure that experienced a typical roof failure. Failure of roof structures at gable ends has been well documented following previous hurricanes, especially when insufficient attention has been paid to connection details at the masonry walls or to bracing the gable end wall. This was the case in Puerto Rico.



FIGURE 3-20 Aerial view of a residential concrete/masonry structure with a wood-frame roof structure; only the roof rafters remain. The wood nailers and metal panels were blown off.

3.4.3 Combination Structures, Concrete/Masonry and Wood-Frame Structures

This construction type was observed almost exclusively in single-family home construction. Concrete columns often supported an elevated concrete slab. CMU block, typically 6-in thick, was used to enclose the lower floor or crawl space area. Wood framing completed the walls and roof structure above the first level. Wood framing was generally inadequate. Nominal 2-in by 3-in lumber was sometimes used for studs. Nominal 2-in by 4-in studs, when used, were often spaced up to 4-feet on center. The studs were generally connected to the wall system by nailing to a bottom plate or sometimes directly to the subfloor. Typically, no connection other than nailing was made from the studs to the floor system. When exterior grade plywood was used as sheathing, it generally did not overlap the band joist. Top plates frequently were made of single, rather than double, 2-in by 4-in members. Rafters generally were supported directly over the studs. No connection other than nailing was made from the walls to the rafter or truss system. Figure 3-21 shows this type of single-family home. While wood-frame construction generally performs well in earthquakes, the other building elements commonly found in Puerto Rico—long slender columns supporting the structure—can lead to the collapse of these structures in a significant earthquake.



FIGURE 3-21 A combination residential concrete/masonry structure with an elevated second-floor concrete slab and a wood-framed upper level. Note the lack of damage to the concrete/masonry section of the house and the damage to the wood-frame portion.

In Figure 3-22, the concrete/masonry building is under construction. Details regarding concrete columns, masonry block, and typical reinforcing steel were observed and noted.



FIGURE 3-22 A residential concrete/masonry structure that is under construction. The photograph illustrates this common building practice: concrete columns with unreinforced masonry block infill walls. This is not seismic resistant construction.

3.4.4 All Wood-Frame Structures

All wood-frame structures were almost exclusively limited to single-family homes. These structures were set atop concrete, masonry, or wood piers and foundations. The load path for wind- and seismic-induced loads from the foundations to the floor systems ranged from bolted steel band connectors to no connectors at all. The walls in these houses were constructed of nominal 2-in by 3-in or 2-in by 4-in lumber. Wall frames were weak with studs spaced up to 4-feet on-center. Sill and bottom wall plates were inadequately fastened to slabs or supporting floors. Stud wall construction contained little to no lateral bracing and only single member top plates. Roof support systems typically were nominal 2-in by 4-in members at 4-feet spacing with nominal 1-in by 3-in nailers supporting metal roof panels. Only a very small number of these structure types had a continuous load path from the roof system to the foundation. Figure 3-23 shows a typical wood-frame home that sustained significant damage during the hurricane.



FIGURE 3-23 A residential wood structure located on the hilltops west of Ponce destroyed by wind. The roof system has been removed and the wall system partially collapsed.